SCIENTIFIC INSTRUCTION:

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Its Aims and Methods.

BY

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SCIENTIFIC INSTRUCTION:
Its Aims and Methods.

The chief objects of teaching science should be to educate the senses, to train the mind to habits of careful, trustworthy, and exact observation of material phenomena, to exercise the judgment in reasoning on those phenomena, their causes, operations, and effects, and to impart a systematic knowledge of the facts and principles of science, of their varied manifestations in the material universe, and of their applications in arts, manufactures, and occupations. While scientific method "is getting more and more power upon the Continent, and while its application there is leading to very considerable results, we in England, having done marvels by the rule of thumb, are still inclined to disbelieve in the paramount importance of any methods but our own. The English notion is, that you come to do a thing right by doing it, and not by first learning how to do it right and then doing it."*

Faraday remarks, that if science is to be taught with success, it must be begun at an early age, because the faculties of youth are plastic, naturally disposed to observation, and to practical manipulation. It is not possible for adult persons to acquire these qualities fully unless they have shown during boyhood a decided predilection for that branch of study.†

In order that boys may learn science with success, they ought to be previously instructed in elementary subjects, and should possess some acquaintance with mathematics, algebra, and geometry. Instruction in physics should precede instruction in chemistry. Boys are best prepared for instruction in Chemical Physics and Chemistry, not by means of introductory popular lectures in these subjects, but by special tuition in mechanics, hydrostatics, hydraulics, pneumatics, the simple properties of matter, etc., which are more elementary in their nature, and therefore precede in point of time the subjects of chemical physics and chemistry. By this plan, also, each teacher has his own distinct subjects and appliances for teaching, and does not require the apparatus employed by another teacher.

The plan of making desultory experiments in a large school, or delivering lectures unaccompanied by frequent tutorial examina-

* Schools and Universities on the Continent. Arnold, 1868, p. 278.
† Life of Faraday, vol. ii. p. 379.

tion, is a very imperfect and unsatisfactory one, especially if the attendance is optional, and the lectures are delivered out of school hours. Such a plan is adopted only in schools where science occupies an inferior position; it produces an unhealthy degree of feverish excitement: the boys attend, not for the purpose of learning, but to see the experiments; and the knowledge imparted is small in amount, fragmentary, and unsystematic. It is well known that the greater the number of explosions and mishaps made by the scientific teacher, the more exciting are the lectures: nothing pleases boys so much as an upset or an explosion. In short, if science is to succeed in our large schools, it must be placed upon a just and honoured footing; the instruction given in it must be systematic, and form a large part of the regular school instruction. "Lectures," says Faraday, "which *really teach* will never be popular, and lectures which are *popular* will never really teach."

A desire for acquiring scientific knowledge is best awakened by means of a systematic series of lessons, illustrated by simple and striking experiments, some of which the pupils can themselves repeat without danger; with simple explanations of the phenomena which occur in the experiments, and illustrating them by similar phenomena which occur in daily life. By these means the boys soon become able to see things of interest around them in all directions. Their minds thus become active and happy, and they acquire a desire for more of that knowledge which has yielded them so much pleasure. One of the most effective experiments of this kind is the preparation of oxygen, and the combustion in it of charcoal and iron wire, and in explaining the ordinary phenomena of combustion in fires and flames. An almost equally effective experiment is the production of chalk by blowing through lime-water, and then explaining the chemical changes which occur in their own respiration. Numerous other simple, effective, and beautiful experiments will occur in illustrating lessons on the subjects of light, heat, electricity, and magnetism. In youth the faculties of inquiry and observation are very active; and to nearly all boys a knowledge of substances, and especially of moving and living things, is most attractive, and shows itself in various ways, such as in making boats, flying kites, keeping animals, etc.; and if these faculties cannot be gratified by means of such subjects as the natural sciences, they will seek exercise (as they now frequently do) in an excess of out of door pursuits, or in some vicious occupation.

The motives for learning science are very various. Many boys

learn it because it is pleasing to see the experiments; some learn because it will be of use in their father's business, or in their destined future occupations, and others simply because they are sent to learn. That would be a comparatively inefficient and imperfect mode of teaching, which would not place scientific knowledge before the minds of the pupils in such a way that every proper motive in a pupil's breast may act as a stimulus to his learning; and for this reason it is desirable that science should be placed before them, as far as possible, in all its aspects.

In this country commercial energy is great; the desire for gain largely swallows up the desire for learning; men wish to see how a knowledge of science will enable them to get money *quickly*. In consequence of this desire, and of the recent transference of some of our trade to foreign nations, there has arisen a demand for some indefinitely understood "technical education," by means of which it is hoped to obtain an easier road to wealth. The extent to which this idea of "technical education" can be carried has been found, in the Polytechnic schools in Germany, to be very limited; science cannot be readily taught in small detached fragments, applicable to single particular trades; it requires to be taught systematically; students must first learn the basis of science without much regard to its practical applications, and afterwards learn the uses of science in the arts. Although a knowledge of science may assist a man to get money, it requires much self-sacrifice in its attainment, and it does not encourage the predominant desire for wealth which so largely characterizes a nation like ours.

Experimental science is not a subject which can be learned off-hand without previous preparation. The different branches of knowledge are so related to each other that they can only be effectually learned in a certain order; namely: instruction in the elements of knowledge precedes, in point of time, all other subjects; physiology cannot be effectually learned by a pupil who is ignorant of chemistry; chemistry cannot be effectually imparted to a pupil who is ignorant of physics. It is beyond the power of man to alter these great natural relations of knowledge to each other and to the human mind. It is absurd to expect to understand scientific lectures fully without a previous acquaintance with scientific terms; we might as well expect to understand a lecture delivered in German without having previously acquired a knowledge of that language. There are no royal roads to knowledge, wealth, or other possessions worthy of attainment.

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Education in England is largely subordinate to the requirements of future examinations;* instead of the whole of a class being well instructed, a portion is being comparatively neglected whilst the other portion is being prepared for examination. Instead of inculcating as the dominant idea the more honourable and lasting motive of a desire to become good and useful men by means of learning, the lower motive of a desire for gain is made too prominent; and the moral standard of the pupils is thereby lowered. Students are led to think that their success in life depends more upon passing certain examinations than in acquiring a permanent possession of useful knowledge. The greatest effects education can accomplish are to produce an accurately instructed and well-balanced mind, and to impart to the pupil a love of knowledge and of self-improvement which shall last as long as he lives. No doubt, with most persons prizes are strong inducements to labour; but when a desire for gain in the shape of honours and rewards is made the *ruling* motive, the desire for knowledge ceases to exist as soon as the reward is attained; this is one of the reasons why men so frequently forget, and find of so little use in after-life, the knowledge they acquired at school. We should adopt far more than we do the plan pursued in Germany: "the paramount University aim there is to encourage a love of study; and the professors, very unlike our college-tutors, are constantly warning their pupils against studies pursued with a view to examinations and posts."† One great reason why science is progressing faster in Germany than in this country, is the higher dominant motive with which it is studied; and if students in that country excel in science by according the greatest influence to the highest motives, surely students in England can.

At the present time, the teachers of science in our large schools are frequently amateurs, and consist, in some instances, of University men and others who have had only a few lessons in the subject before they commenced to teach; some are men possessed of a fair knowledge of science, but without experience: the result is defective teaching. At the present time, also, some of the scientific professorships in our colleges are held by men who pursue science as a means of living, and make no original investigations. Were such appointments conferred only on men who pursue science primarily

* Everything in the way of improvement in the *curricula* of middle-class schools naturally depends on the requirements of the higher schools, the Universities, and the public service. Let those be made more rational and practical, and then progress will become possible.

† Schools and Universities on the Continent.—*Arnold*, p. 230.

from a love of the subject, the cause of scientific education would be greatly promoted. The teacher should have a higher dominant motive for labour than the pursuit of money. Mr. Faraday, speaking as a scientific man, said, "I cannot afford to get rich."* To make a trade of science, to make personal emolument the most important object, shows an ignorance of the very nature of science which is inexcusable in a teacher; science is essentially a pursuit of truth, not of money. By examining any University or public school calendar, it will be seen how very small a proportion of our teachers of science are men of scientific eminence.†

The most perfect guarantees of efficiency in a teacher of science, are a thorough love and knowledge of his subject, with long experience in teaching. The most infallible test of the first of these qualities is his pursuit of that portion of the subject which requires the greatest self-denial and skill, viz., original experimental research.

Faraday, in his evidence before the Royal Commission, stated that the class of men suitable for teaching science "hardly exist, at present."‡ This statement still continues true; our old Universities have not yet supplied many schools with teachers eminent in physics or chemistry; but in response to the sudden public demand for some indefinitely understood scientific education, have sent forth teachers possessing but little experience in making experiments, much less acquaintance with the relations of science to manufactures, and almost entirely without experience in original experimental research. The ignorance of scientific method, and of some of the simplest practical matters in experiments, shown by some of these scholastic gentlemen, has been quite astonishing, and the most charitable supposition is, that they are unaware of their ignorance.

Habits of trustworthy and exact observation of physical and chemical phenomena, can only be imparted by prolonged series of lessons, freely illustrated by experiments, processes, apparatus, models, drawings, diagrams, and the use of the black-board. The lessons should be at regular and not too wide intervals. At each lesson the pupils should be examined *viva voce* on the subject of the preceding lessons, and periodical examinations by means of written papers should also be held. During the lessons, the pupils should accurately observe all the particular phenomena pointed out by the teacher, and take notes of all the chief

* Life of Faraday, vol. ii. p. 423.

† Science Normal Schools, where specific degrees or certificates are procurable, form the grand desideratum.

‡ Royal Commission on Public Schools, vol. iv. p. 376.

facts, principles, and illustrations; they should also make sketches of the apparatus and experiments. These notes may with advantage be corrected by the teacher. The teacher should be very careful, when making any dangerous experiments, to impress upon his pupils the precautions necessary to avoid accidents

Habits of trustworthy and exact observation are best imparted by a teacher accustomed to original research. A teacher who only repeats the experiments of others, sees only the way in which the experiment under the exact conditions stated will succeed, and does not adequately realize the numerous ways in which, through slight unavoidable variations in the conditions, it frequently fails or produces unexpected results; with every experiment, when there is one way of succeeding, there are always many ways of failing. Descriptions in books usually state only the ways of succeeding, and omit to enumerate the numerous interfering conditions and causes of failure, because of its making the description tedious.

Many class experiments require long experience, because every different substance possesses different properties, and requires different treatment; and every dissimilar experiment, even with the same substance, requires a dissimilar combination of conditions to ensure success. Even with the greatest care and experience, experiments will sometimes partly fail, through want of pure materials or imperfect apparatus; such unsuccessful experiments should be repeated at the next lesson.

Very frequently indeed ordinary chemicals contain impurities; and every chemist of considerable experience knows that highly pure substances are the exception, rather than the rule, partly in consequence of the difficulty of separating the numerous adventitious matters. In consequence of these impurities, the results obtained in chemical experiments by insufficiently experienced teachers are often ludicrous to their pupils and very confusing to themselves: for instance, the teacher announces that a precipitate will be white, when, lo and behold! in consequence of the presence of a little unsuspected salt of iron, it is black!! The number of impurities which some of the ordinary chemicals are liable to contain, is quite surprising; for example, common fluoric acid, in addition to containing water, which is not considered an impurity in it, is liable to contain sulphuric acid, sulphurous acid, hydrofluosilicic acid, hydrochloric acid, arsenic, lead, iron, thallium, lime, potash, soda, and several other matters, and it is hardly to be purchased in a pure state. As every different substance present affects the properties of a body,

it is essential that the teacher be extensively acquainted with these constantly occurring interfering substances, and their probable influence upon his experiments; and every careful teacher will inform his pupils, before making an experiment, what interfering conditions are likely to be present, and what influence they will have upon the results.

The number of boys that can be efficiently taught experimental science in a single class, without the aid of an assistant, is considerably less than in other classes, where experiments are not required, because the teacher has the double duty of keeping his class in order, and making experiments which are frequently critical and sometimes dangerous. For this reason, science can only be effectually taught to a class of boys in which a high degree of discipline is maintained.

A teacher from one of our old Universities has suggested to me that experiments might perhaps be "too numerous." The advice of Faraday to the teacher of science was, to show experiments and apparatus, in illustration of a principle, whenever possible. Where there are but few experiments, there is insufficient exercise of the faculties of observation, and the teaching is much less effective. As the object of school education is to train as well as to teach, and as boys have to grow to be men, it is manifest that less efficient discipline than that required for men is not good enough for boys. It is not the indiscriminate exhibition of experiments that most successfully imparts instruction, but the judicious distribution of well chosen ones to illustrate general principles in systematic series of lessons.

Experiments are most powerful teachers; they impress the mind with a degree of reality which no description, however lucid, can possibly convey. It is more easy to fix the attention upon visible things than upon abstractions, especially if the object is in motion, or emits light or sound; and memory in all persons is stronger and more lasting, in proportion to the strength and vividness of the original impression. In experiments, also, the substances speak, as it were, for themselves, and no belief of the teacher can make the results different. Apparatus and models, and even diagrams alone, in cases where experiments cannot be shown, have a somewhat similar effect, but in a less degree. Some teachers who are accustomed to teach non-scientific subjects by means of books alone, do not like to soil their hands by making experiments. I once asked a teacher from one of our old Universities, who professed to understand chemistry, why he did not fit up a small laboratory, and gain

experience by making experiments; and his reply was, "I do not like the drudgery."

In addition to seeing experiments, it is of great advantage to pupils to have an opportunity of occasionally visiting large manufactories, in company with their teacher, and seeing in operation the principles of physics and chemistry on a large scale, and having explained to them the manipulations and processes: they thus acquire an idea of the great and indispensable value of science in industrial operations, and receive an additional stimulus to learning. It is also beneficial to accustom the pupils to observe the phenomena of physics and chemistry as they occur upon a large scale, in the phenomena of the earth, the sea, and the atmosphere, the changes indicated by a barometer, etc.

Notwithstanding the great value of experience in original experimental investigation, as a discipline to the teacher of science, it has been extremely neglected in this country, and we possess no colleges or other establishments in which such experience is systematically provided, or in which it is even assisted. All those who wish to acquire such discipline have to make great sacrifices for its attainment; and the result is that a great many of our scientific teachers do not acquire it at all, and are very unreliable and inaccurate. In Germany, the case is different; there the students are encouraged and aided by the Government in the prosecution of scientific research. In the large State laboratory at Berlin, a portion of the building is specially set apart for that purpose.*

The difficulty of obtaining a sufficient number of properly qualified scientific teachers, under the present circumstances, is very manifest. But if science was properly encouraged in this country, the case would be different: many young men possessed of natural scientific ability, who are now obliged to abandon the pursuit of science for want of proper remuneration, would be glad to devote themselves to teaching and to original research, and thus a sufficient supply of properly qualified teachers would be obtained.

In addition to the training of the senses and of the mind which a pupil receives by means of lessons in experimental science, he should be disciplined in manipulation, by making physical and chemical experiments and chemical analyses. "Lectures alone cannot be expected to give more than a general idea of this most

* Kensington and Jermyn Street Museums, the College of Chemistry, the Albert Hall, and *all* our Mechanics' Institutions, might be rationally utilized, provided only qualified teachers of science existed. Query: Why do they not exist?—Ed.

extensive branch of science [chemistry], and it would be too much to expect that young men who, at the utmost, have only attended fifty lectures on chemistry, should be able to answer with much effect, in writing, to questions set down on paper, when we know by experience that daily work for eight hours in *practical laboratories* for *three months* does not go very far to confer such ability." *

Boys (and men also) who only *see* experiments performed, frequently get the false impression that science in general is an easy thing, because they see the teacher make experiments so readily; but the experiments selected for use in lectures are generally of the easiest kind and such only as can be quickly performed and give conspicuous results, visible at a distance, and are not by any means a fair specimen of the every-day occupation of scientific men, or of science in general, such as is continually required, not only for theoretic purposes, but also for the determination of numerous practical questions of importance in commercial, manufacturing, engineering, agricultural, military, naval, and other affairs.

* Life of Faraday, vol. ii., p. 29.

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